RCP-Planet: A Rate Control Scheme for Multimedia Traffic in InterPlaNetary Internet

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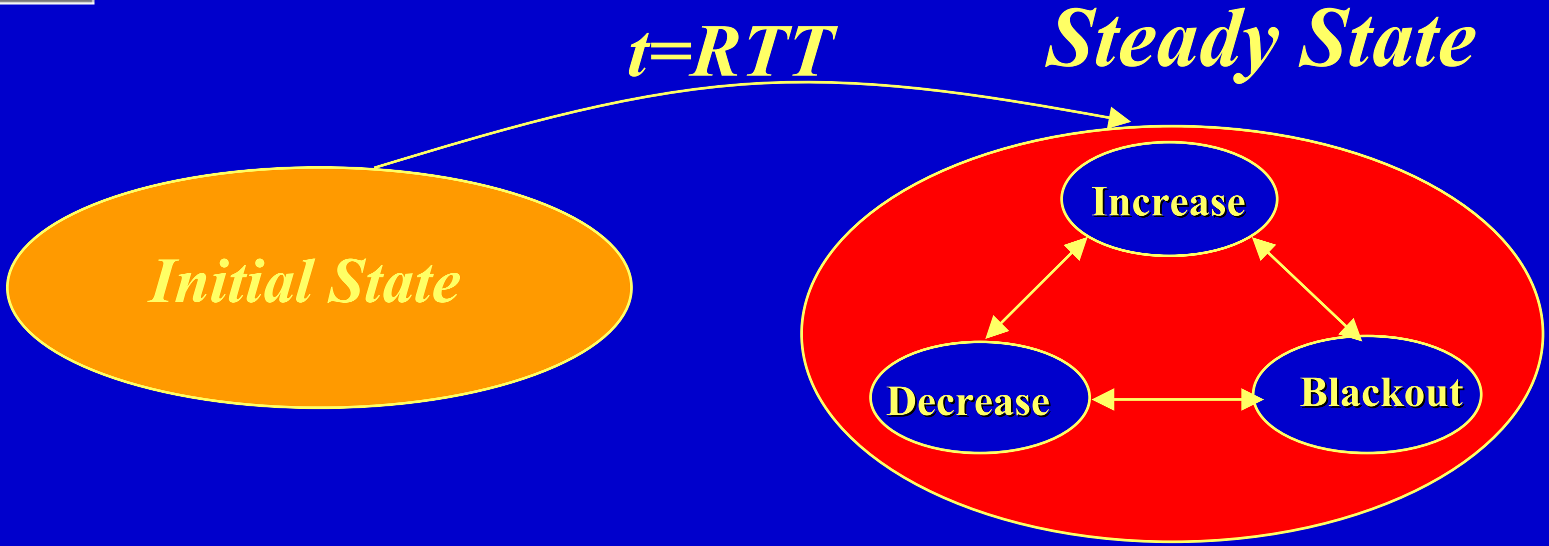
Challenges

- Extremely Long Propagation Delays
- High Link Error Rates
- Bandwidth Asymmetry
- Blackout Problem

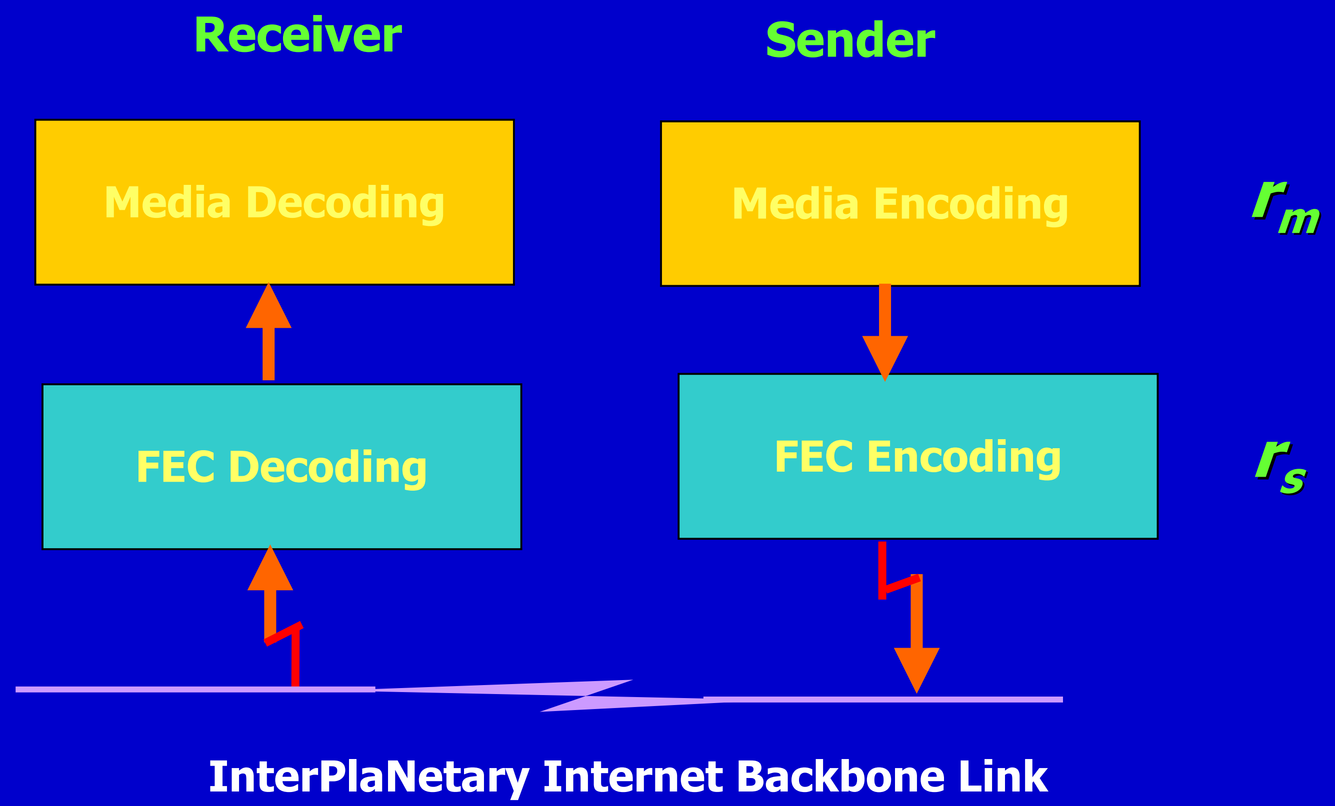
- Requirements of Multimedia Traffic
  - Bounded Jitter
  - Minimum Bandwidth
  - Smoothness

RCP-Planet Overview



- ***Objective:*** **To Address the Challenges**
- ***Framework:***
  - **** A New Packet Level FEC***
  - **** A New Rate-based*** **Approach**
  - *** A New *Initial State* Algorithm**
  - *** A New Rate Control Algorithm in *Steady State***

Packet Level FEC



- Media rate r_m is the data rate from the application
- r_s is the source sending rate
- $r_s = r_m \cdot n/d$

Packet Level FEC (*Tornado Codes*)

- Tornado codes *FEC (n,k)* are used for packet level FEC
  - * *n* is the FEC block length
  - * *k* is the number of packets required to recover a block

- Advantage:
  - Very fast encoding and decoding speeds
- Disadvantage:
  - Require slightly more packets to recover a FEC block

- Original data length *d* must be chosen appropriately to minimize the total FEC Overhead → (n-d).

Initial State (*FEC Redundancy*)

Challenges:

- **FEC Redundancy:** Packet loss rate p is unknown
- **Initial Rate:** Available bandwidth is unknown

FEC Redundancy

- Use most recent history value p_h to determine the FEC block length n.
- *Assume* → $p_l >> p_h$ for possible worse network condition
  - * Calculate the FEC block length n'.
  - * Use n' as the actual FEC block length to encode data.
- For one FEC block, send n packets and the remaining $(n'-n)$ packets in low priority.
- Address the worse network condition by sending more redundancy.
- However, part of the redundant packets are sent in low priority so that they will not affect the actual data traffic.

Initial State
(Setting the Initial Rate)

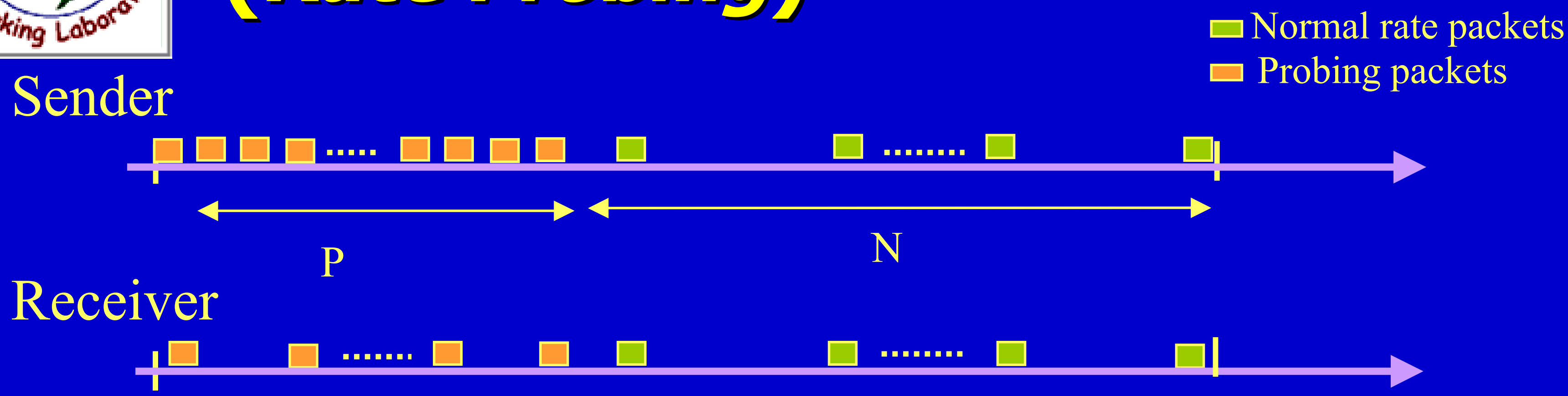
– The initial media rate $r_{m,init}$ is conservatively set to a minimum rate required by an application.

– The initial sending rate $r_{s,init}$ is then

$$r_{s,init} = r_{m,init} \cdot n/d$$

* n is the FEC block length
* d is the original data length

Initial State (*Rate Probing*)



- To determine the available bandwidth, a probing scheme is used in both INITIAL and STEADY STATES.
- In each FEC block, we first send a fixed number of packets, called *a probing sequence*, at a so-called *probing rate* r_p much higher than the initial source sending rate $r_{s,init}$.
- The remaining packets are sent using $r_{s,init}$.
- The observed rate r_o for the probing sequence at the receiver side is the available bandwidth.
- If $r_p > r_o \rightarrow$ some probing packets will be dropped.
- After *one RTT*, the receiver will send one ACK for each FEC block back to the sender which includes r_o and the current packet loss rate.

Steady State

- ***A Rate Adaptation Scheme*** **to update probing rate based on the network condition**
- **A New *Rate Control Scheme***
- ***Blackout State*** **to address the link outages**
- ***Block Level ACK*** **to address the Bandwidth Asymmetry problem**

Steady State
(*The Rate Adaptation Scheme for Probing*)

- The receiver reports the observed rate for each probing sequence back to the sender.
- The variance of the observed rate is used as an indication of the degree of congestion.
- The probing rate is then decreased during congestion.
- The current probing rate $r_{p,i+1}$ is updated as

$$r_{p,i+1} = r_{m,\max} \frac{n}{d} \left(1 - \frac{V_{o,i+1}}{E_{o,i+1}}\right)$$

where $r_{m,max}$ is the maximum media rate
$E_{o,i+1}$ is the current mean of the observed rate
$V_{o,i+1}$ is the current variance of the observed rate

$$E_{o,i+1} = \gamma E_{o,i} + (1-\gamma) r_{o,i+1}$$
$$V_{o,i+1} = \gamma V_{o,i} + (1-\gamma)(r_{o,i+1} - E_{o,i+1})^2$$

with γ is the forgetting factor, usually chosen as *0.95*

Steady State
(The New *Rate Control Scheme*)

- The available media rate $r_{a,i+1}$ (the upper bound of the current media rate) is updated based on the current observed rate $r_{o,i+1}$

$$r_{a,i+1} = r_{o,i+1} \bullet \frac{d}{n}$$

- *If* $r_{a,i+1} \geq r_{m,i}$ (the current media rate), then

$$r_{m,i+1} = \frac{1}{2}\left[r_{m,i} + \sqrt{r_{m,i}^{2} + 4d\left(\frac{r_{a,i+1} - r_{m,i}}{RTT}\right)} \right]$$

- *If* $r_{a,i+1} < r_{m,i}$ *, then*

$$r_{m,i+1} = r_{m,i} \bullet \beta$$

* β is a constant smaller than *1*

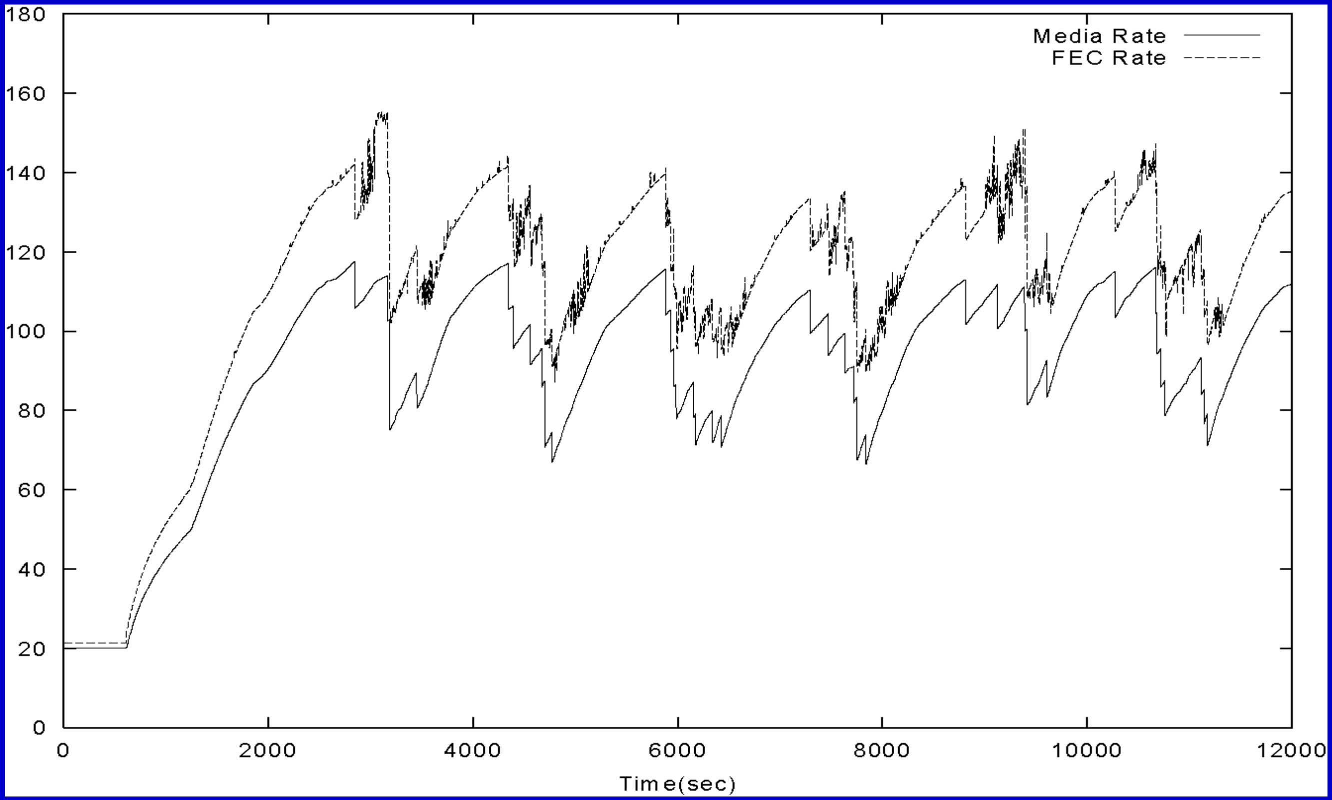
Steady State
(Blackout State)

- If the sender does not receive an ACK for a certain period T_w → it goes to *Blackout State*
- Blackout State
  - *Objective:* To reduce the throughput degradation due to blackout.
  - Source stops sending new data packets.
  - Receiver keeps sending ACKs including the observed rate r_o and the packet loss rate p.
  - If the source starts to receive ACKs with $(r_o=0, p=1)$, then it starts to send packets with the same rate just before the blackout.

Steady State
(Bandwidth Asymmetry)

- ACK for each packet leads to congestion in the reverse link for asymmetrical space links
- Block Level ACK
  - For each FEC block, the receiver only sends one ACK to report the observed rate and current packet loss rate.
  - Delayed ACK can also be used to further reduce the number of ACKs.

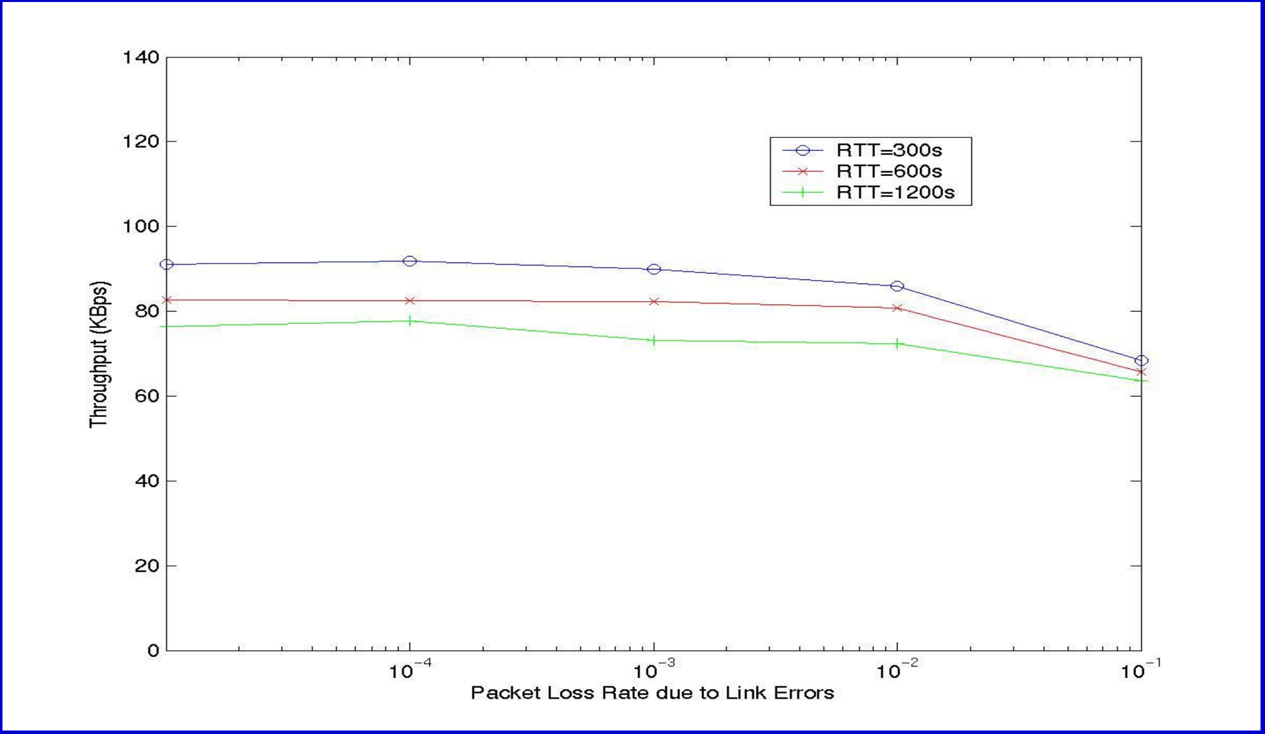
Performance Evaluation (*Media and FEC Rate*)



Media and FEC Rate

(*10* RCP connections, RTT= *600* seconds, p= *10^{-4}*, Minimum Media Rate: *20KB/s*, Maximum Media Rate: *140KB/s*, Link Speed: *1300 KB/s*, Duration= *12000* seconds)

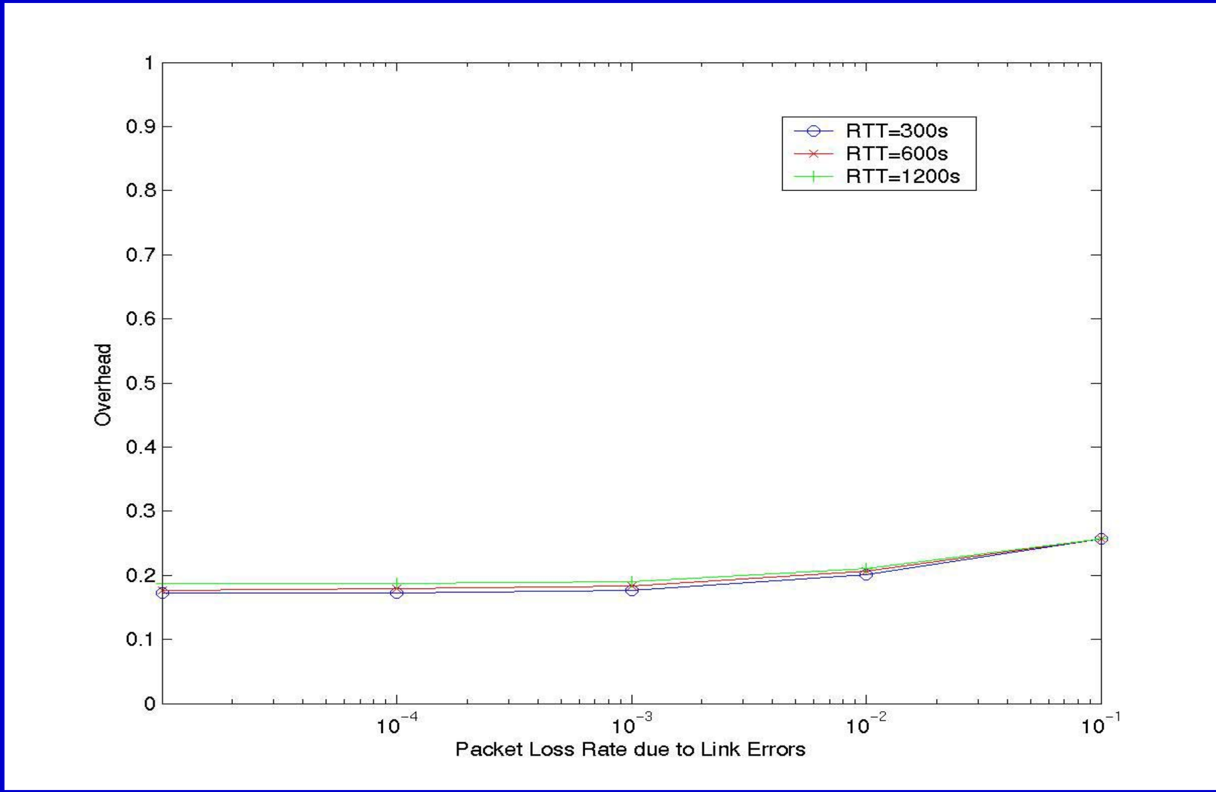
Performance Evaluation (*Throughput*)



Throughput vs. Packet Loss Rate due to Link Errors

(10* RCP connections, RTT=*300, 600, 1200* sec, p=*10^{-5} - 10^{-1}*, Minimum Media Rate: *20KB/s, Maximum* Media Rate: *140KB/s,* Link Speed: *1300 KB/s,* Duration= *10 RTTs)

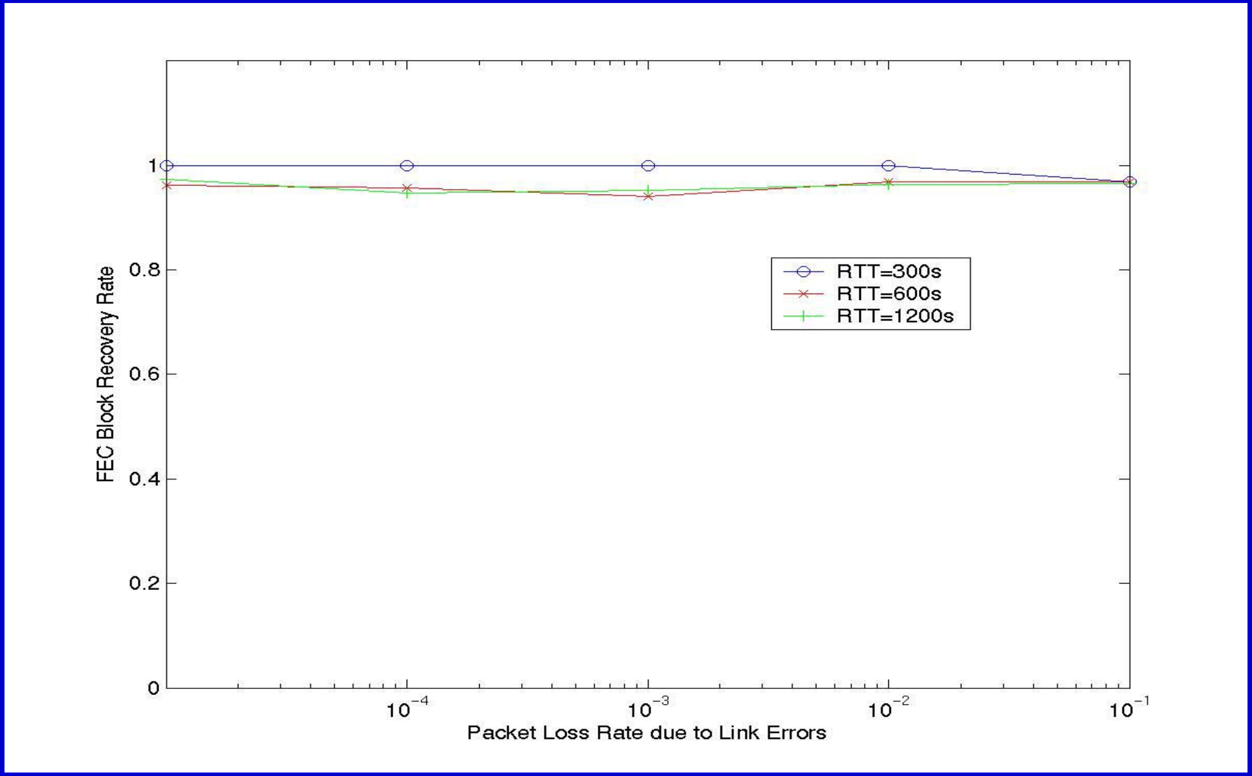
Performance Evaluation (*Overhead*)



Overhead vs. Packet Loss Rate due to Link Errors

(*10* RCP Connections, RTT=*300, 600, 1200* sec, p=*10^{-5} - 10^{-1}*,
Minimum Media Rate: *20KB/s, Maximum M*edia Rate: *140KB/s*,
Link Speed: *1300 KB/s,* Duration= *10 RTTs)*

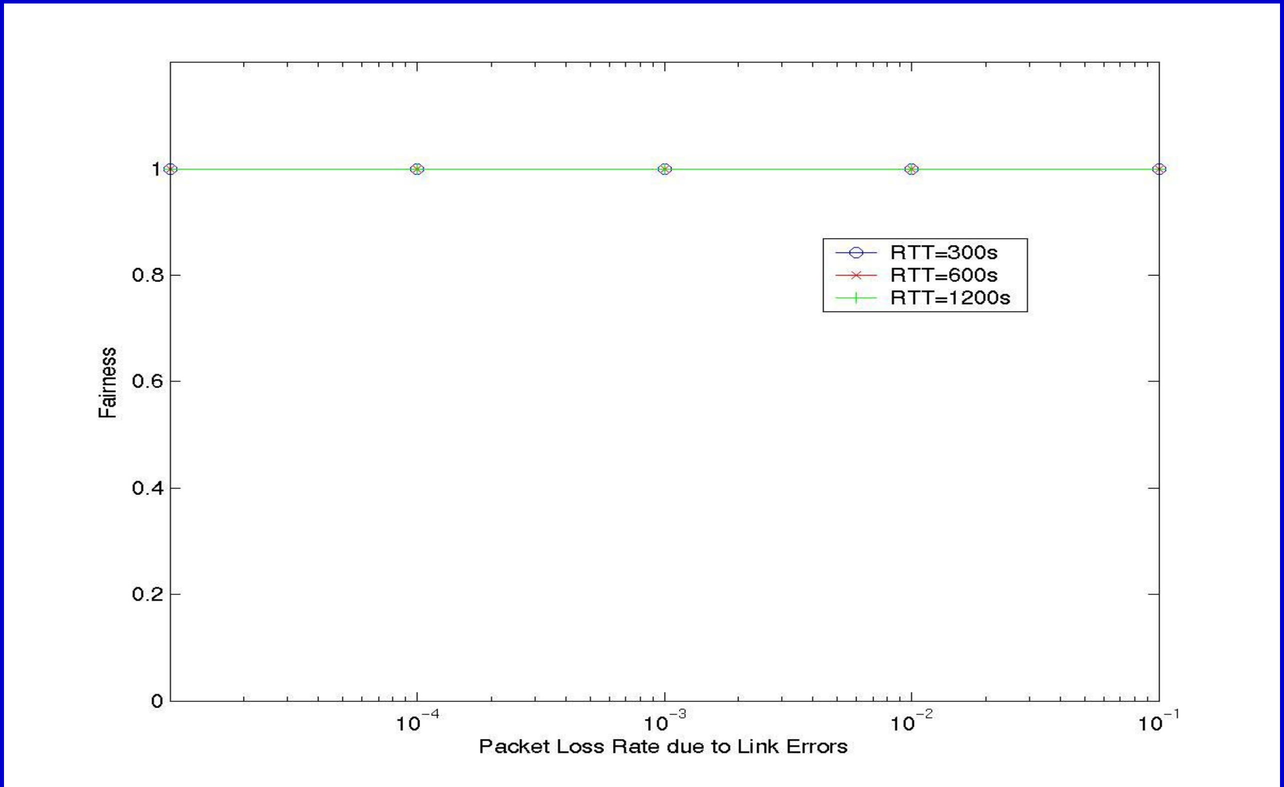
Performance Evaluation (*FEC Block Recovery Rate*)



FEC Block Recovery Rate vs. Packet Loss Rate due to Link Errors

(*10* RCP Connections, RTT=*300, 600, 1200* sec, p=*10^{-5} - 10^{-1}*, Minimum Media Rate: *20KB/s, Maximum* Media Rate: *140KB/s,* Link Speed: *1300 KB/s,* Duration= *10 RTTs)*

Performance Evaluation (*Fairness*)



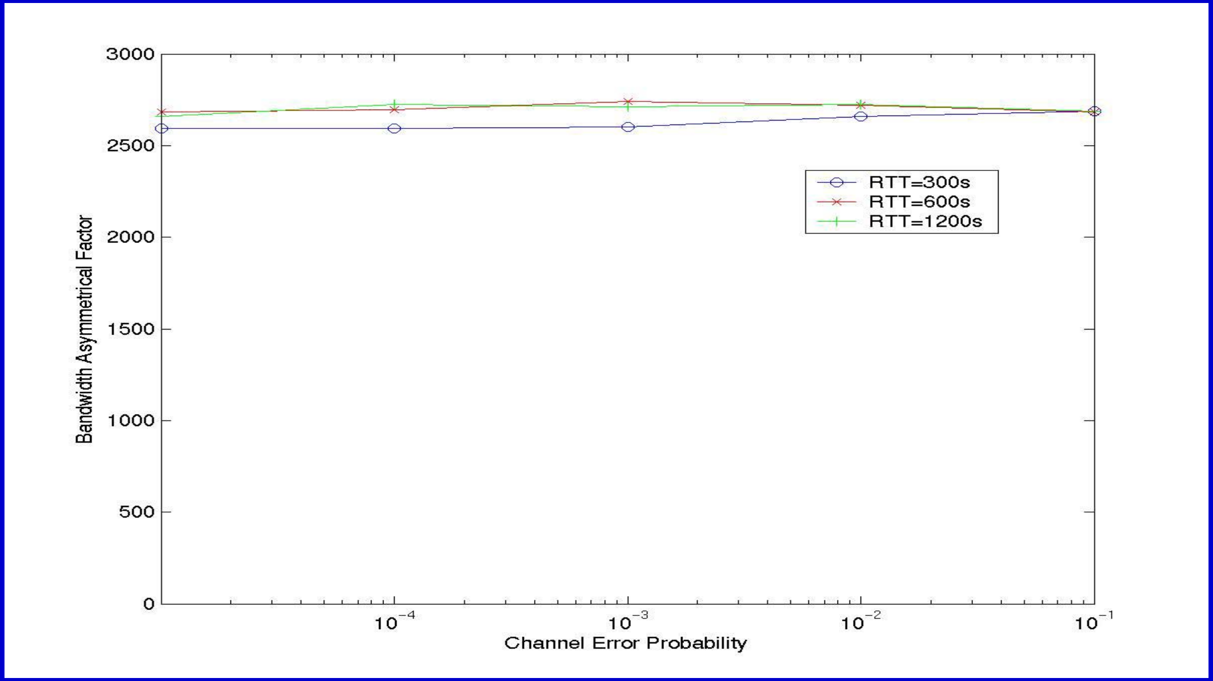
Fairness vs. Packet Loss Rate due to Link Errors

(1*0* RCP Connections, RTT=*300, 600, 1200* sec, p=*10^{-5} - 10^{-1}*, Minimum Media Rate: *20KB/s, Maximum Media Rate*: *140KB/s,* Link Speed: *1300 KB/s,* Duration= *10 RTTs)*

Performance Evaluation

(*Bandwidth Asymmetry Factor*)

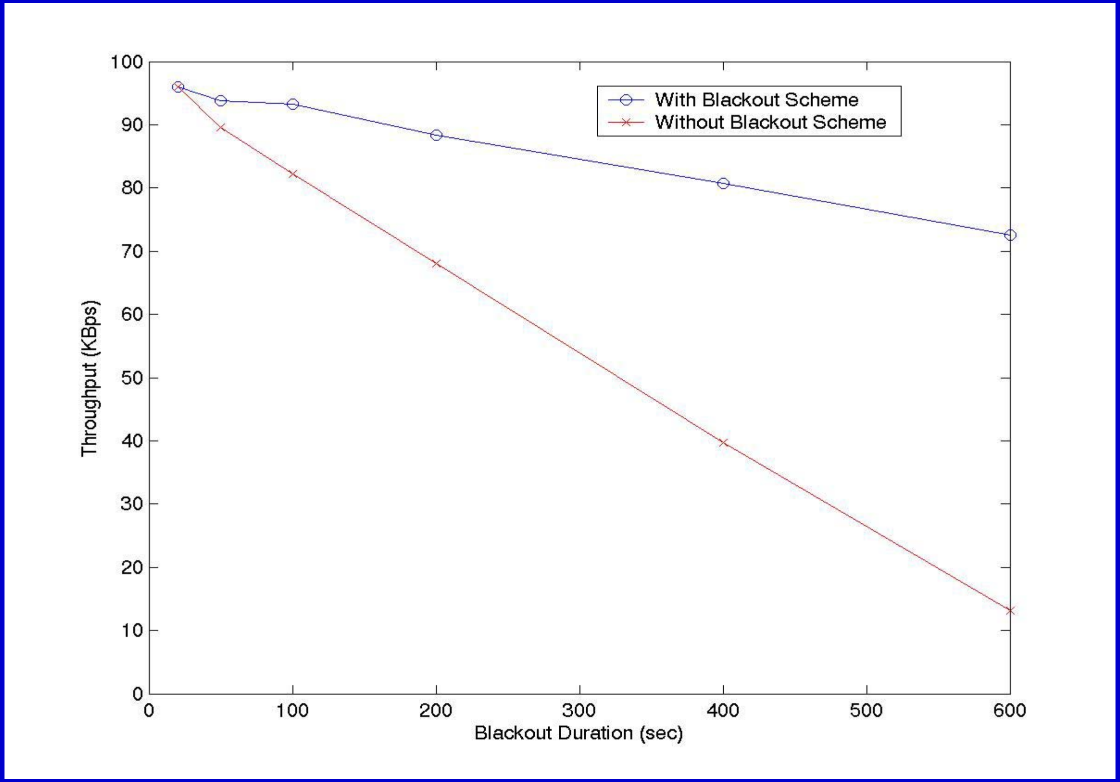
$$f = \frac{Number\ of\ Packets\ \mathrm{Re}ceived \bullet Packet\ Size}{Number\ of\ ACKs\ Sent \bullet ACK\ Size}$$



Bandwidth Asymmetry Factor vs. Packet Loss Rate due to Link Errors

(10 RCP connections, RTT=*300, 600, 1200* sec, p=*10^{-5} - 10^{-1}*, Minimum Media Rate: *20KB/s,Maximum Media Rate: 140KB/s,* Link Speed: *1300 KB/s,* Duration= *10 RTTs)*

Performance Evaluation (*Blackout Performance*)



Throughput vs. Blackout Duration

(RTT=*600* sec, p=*10^{-4}*, Minimum Media Rate: *20KB/s*, *Maximum Media Rate*: *140KB/s*, Link Speed: *1300 KB/s*, *Simulation* Time= *6000 sec*)

Conclusions

- RCP-Planet is introduced to address the challenges in the InterPlaNetary Internet.
- RCP-Planet Framework
  - Initial State Algorithm
  - Rate Control Scheme based on Rate Probing
  - Blackout State to address link outages
  - Block Level ACKs for Bandwidth Asymmetry
- Performance evaluation shows RCP-Planet addresses the challenges and achieves high throughput and fairness.